Evaluation of satellite data assimilation impacts within the hourly cycled Rapid Refresh

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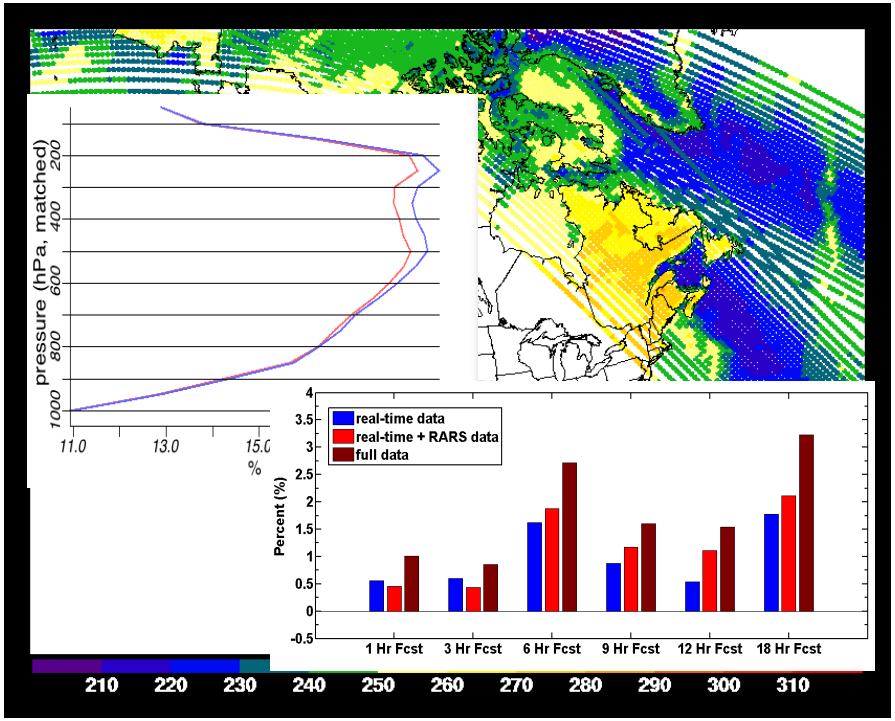


Presentation Outline

1. **Background on Rapid Refresh (RAP) system**
2. **Background and difficulties on regional radiance assimilation**
   - → **satellite data types (geo / LEO, IR / microwave)**
   - → **bias correction, channel selection, latency**
3. **Satellite radiance experiments**
   - ➢ **AIRS and GOES impact in RAP (retrospective)**
     - upper air and precipitation verification
   - ➢ **Sensitivity to data latency (retrospective)**
     - upper air and precipitation verification
   - ➢ **Real-time radiance impact in RAP**
     - upper air verification and impact on HRRR (retro)
4. **Summary and future work**

Background on Rapid Refresh

NOAA/NCEP's hourly updated model

RAP version 1 -- NCEP since Spring 2012

- Advanced community codes (ARW model, GSI analysis)
- Key features for short-range "situational awareness" application (cloud analysis, radar DFI assimilation)

➔ RAP guidance for aviation, severe weather, energy applications

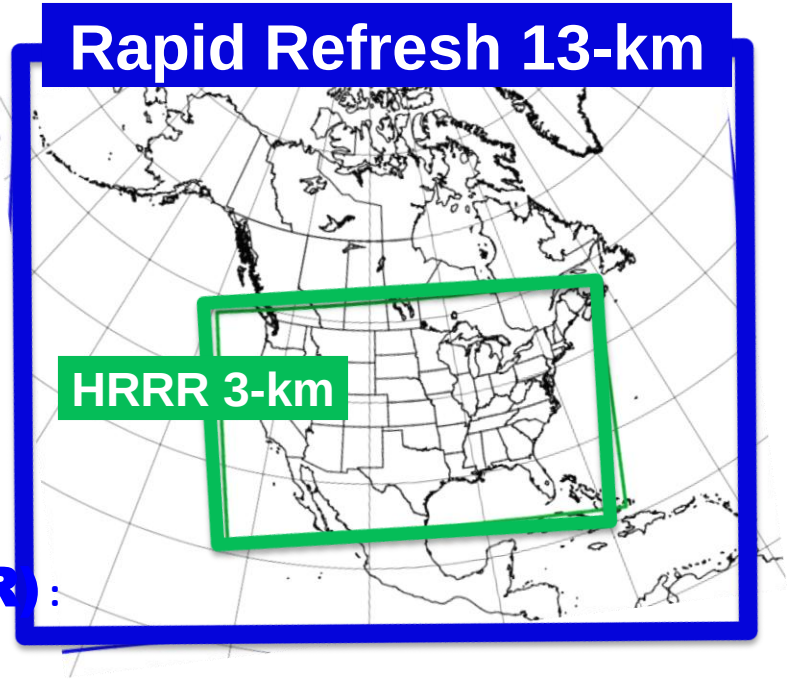
RAP version 2 -- implemented NCEP 25 Feb. 2014

- DA enhancements (Hybrid – EnKF using global ensemble)
- Model enhancements (MYNN PBL, 9-layer LSM)

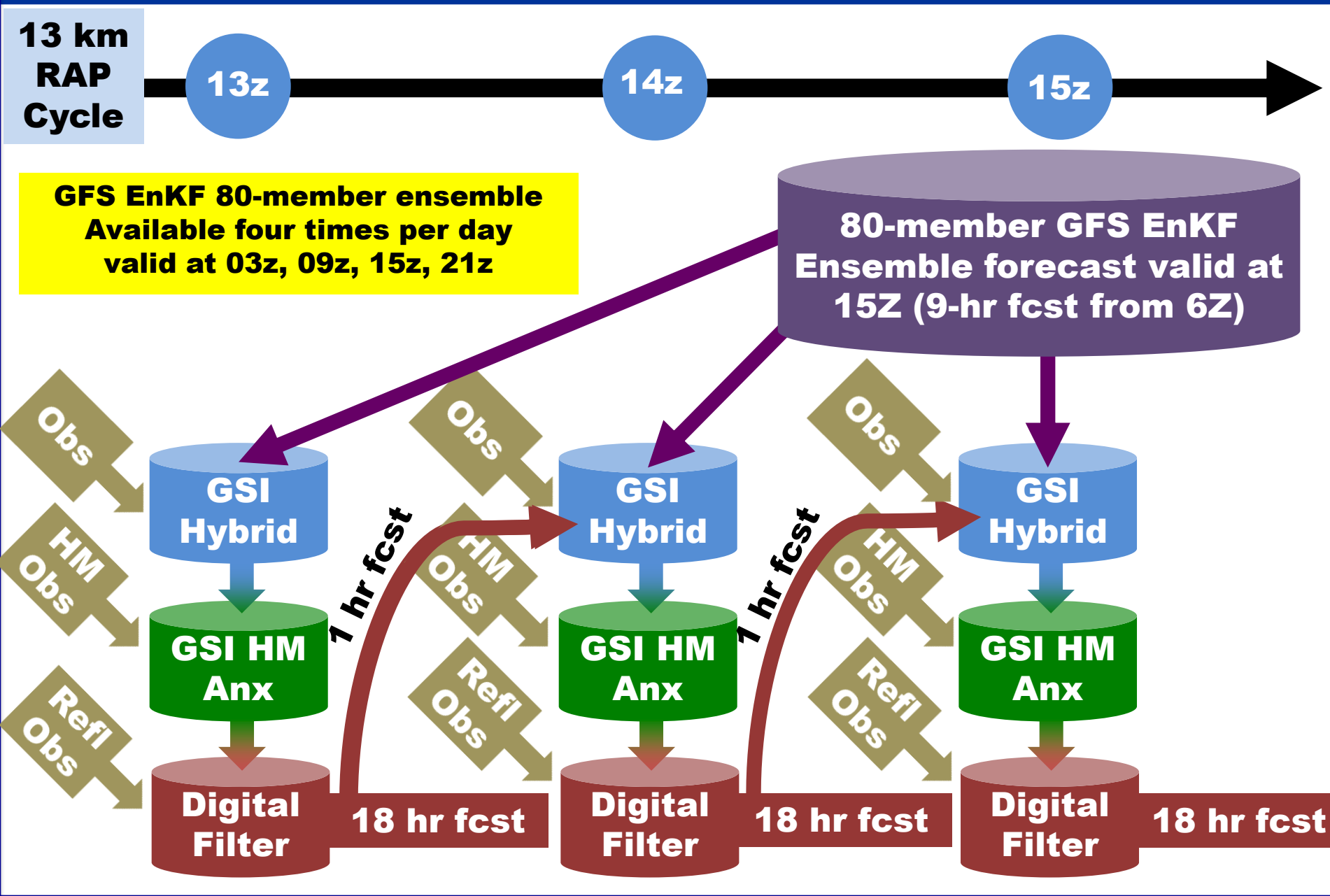
RAP version 3 -- planned implementation in 2015

High Resolution Rapid Refresh (HRRR):

NCEP implementation planned for later 2014



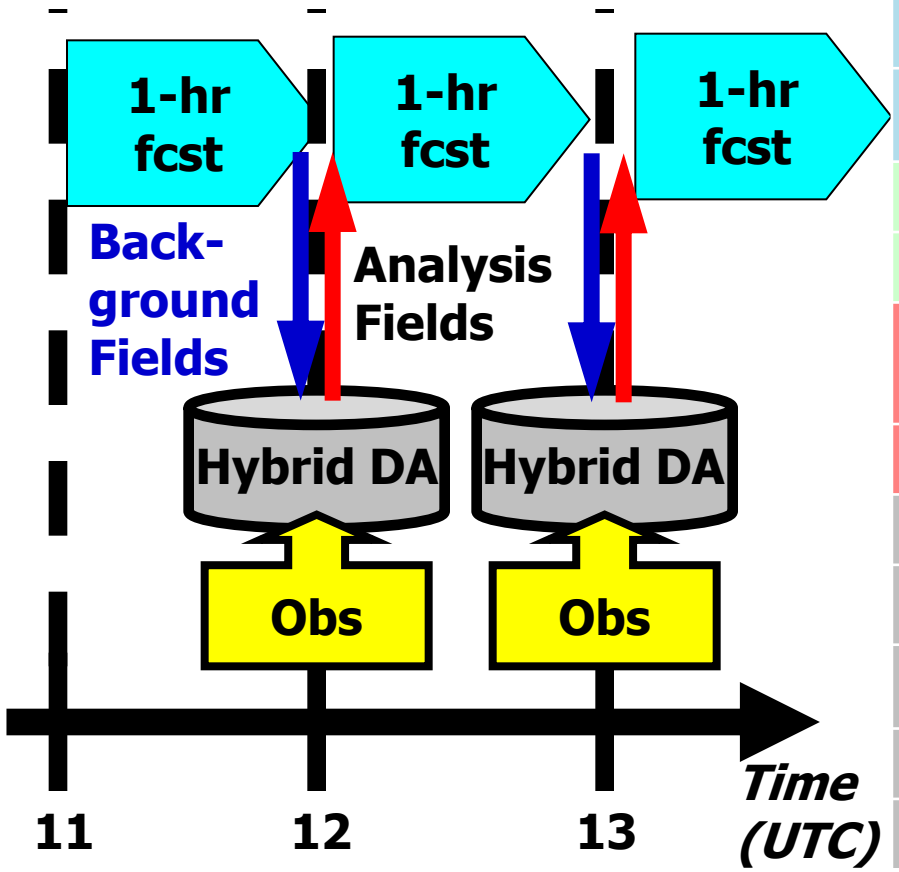
RAPv2 Data Assimilation



Rapid Refresh Hourly Update Cycle

Partial cycle atmospheric fields – introduce GFS information 2x/day

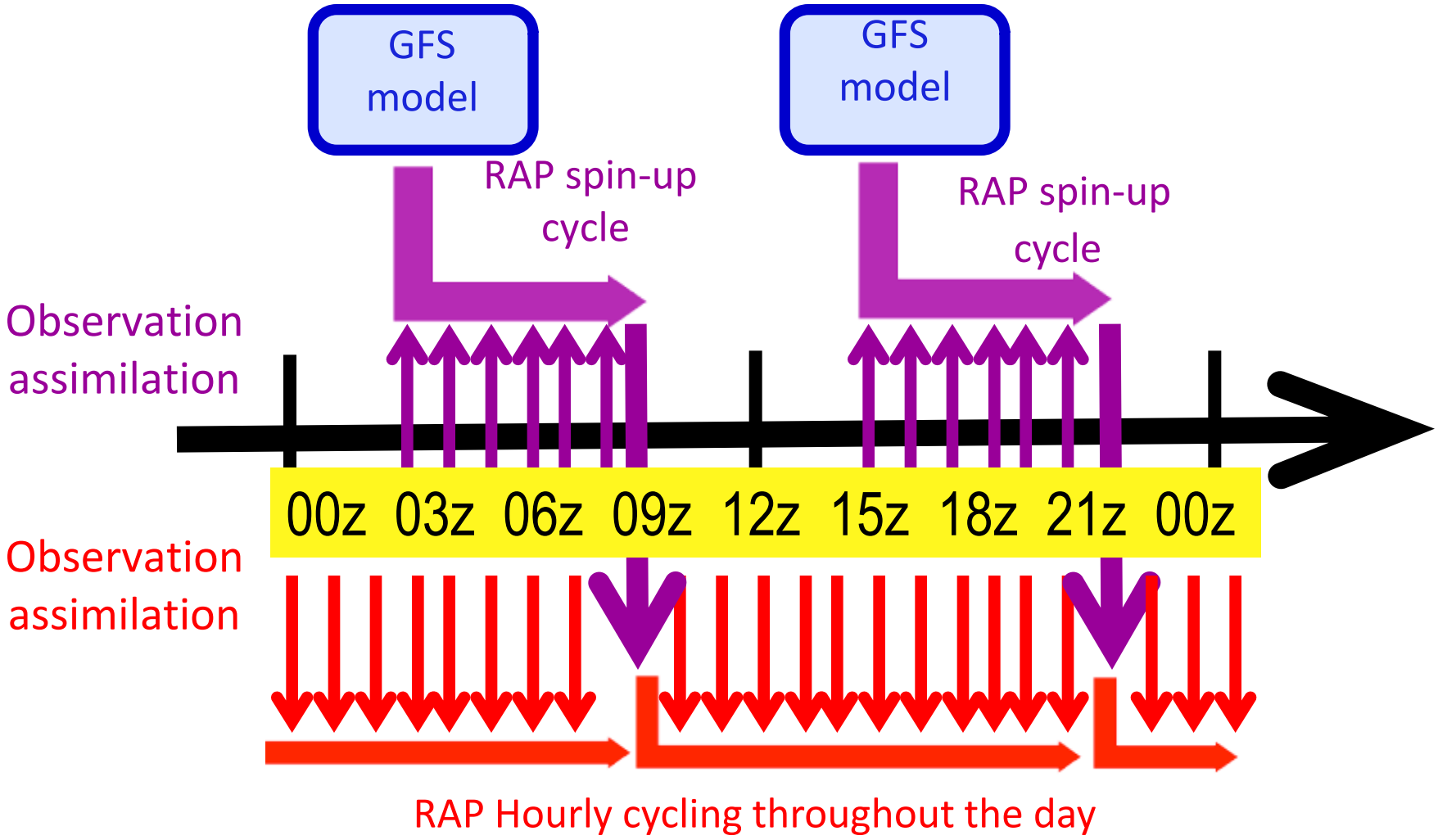
Fully cycle all land-sfc fields



Observations Used

Hourly Observations	RAP 2014 N. Amer
Rawinsonde (T,V,RH)	120
Profiler – NOAA Network (V)	21
Profiler – 915 MHz (V, Tv)	25
Radar – VAD (V)	125
Radar reflectivity - CONUS	1km
Lightning (proxy reflectivity)	**NLDN, GLD360**
Aircraft (V,T)	2-15K
Aircraft - WVSS (RH)	0-800
Surface/METAR (T,Td,V,ps,cloud, vis, wx)	2200- 2500
Buoys/ships (V, ps)	200-400
GOES AMVs (V)	2000- 4000
AMSU/HIRS/MHS radiances	Used
GOES cloud-top press/temp	13km
GPS – Precipitable water	260
WindSat scatterometer	2-10K

Rapid Refresh Partial Cycling



- Hourly cycling of land surface model fields
- 6-hour spin-up cycle for hydrometeors, surface fields

Radiance Data

- **AMSUA (used in operational RAP)**
  - Temperature and moisture information
- **MHS (used in operational RAP)**
  - Temperature and moisture information
- **HIRS4 (used in operational RAP)**
  - Temperature information
  - Moisture information (channels 10-12)

- **AIRS (not in operational RAP, testing data)**
  - High vertical resolution (hyperspectral)
  - Temperature and moisture information
- **GOES (not in operational RAP, will be in RAP V3)**
  - Temperature and moisture information
  - Good hourly real-time coverage

Radiance Assimilation for RAP

Challenges for regional, rapid updating radiance assimilation

- **Bias correction**
  - **-- Sophisticated cycled predictive bias correction in GSI**
  - **-- Spin-up period, complicated by non-uniform data coverage**
- **Channel Selection**
  - **Many channels sense at levels near RAP model top (10 mb)**
  - **Use of these high peaking channel can degrade forecast**
  - **Jacobian / adjoint analysis to select channels for exclusion**
- **Data availability issues for real-time use**
  - Rapid updating regional models: short data cut-off, small domain
  - Above combined with large data latency ➔ little data availability
  - Complicates bias correction, partial cycle assimilation options

Variational Satellite Bias Correction in GSI

$$J(x,\beta) = \tfrac{1}{2}(x - x_b)^T B^{-1}(x - x_b) + \tfrac{1}{2}(\beta - \beta_b)^T B_\beta^{-1}(\beta - \beta_b)$$

$$+ \tfrac{1}{2}[y - \tilde{H}(x,\beta)]^T R^{-1}[y - \tilde{H}(x,\beta)]$$

B_β Bias parameter background error covariance matrix

$$\tilde{H}(x,\beta) = H(x) + \sum_{i=0}^{N} \beta_i p_i(x) + \beta^{scan}$$

Observation Operator (CRTM)

Air mass bias

Angle bias

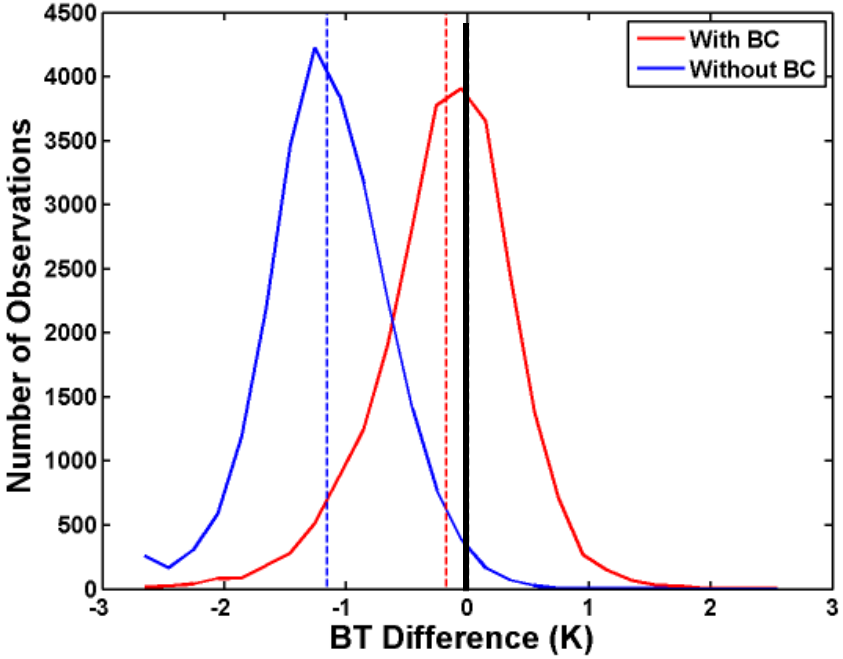
β_i are the coefficients of predictors (updated at every cycle)

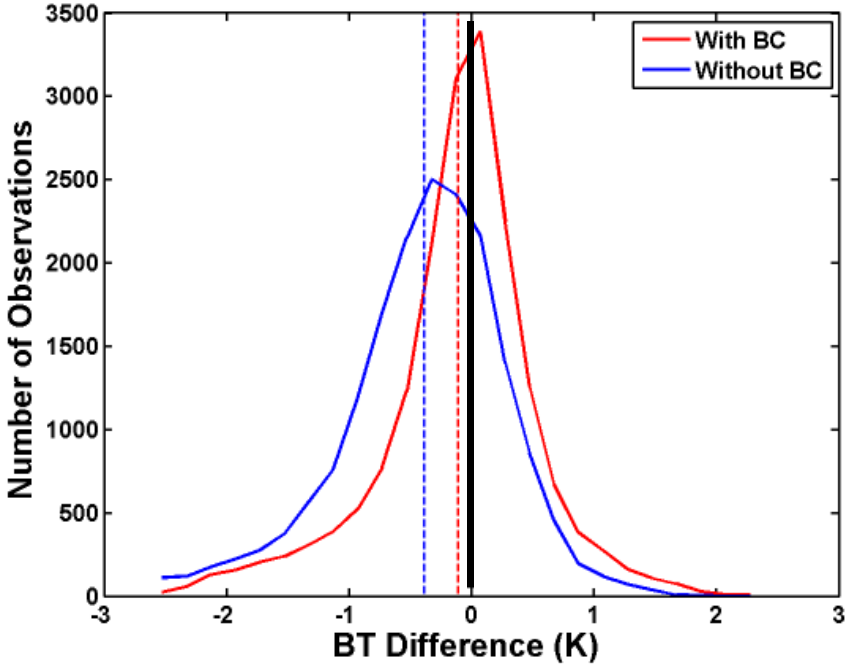
p_i = **predictors**

- mean constant (global offset)
- scan angle
- cloud liquid water (for microwave)
- square of T lapse rate
- T lapse rate

(Derber et al., 1991, Derber and Wu, 1998)

AIRS Bias Correction Assessment





Before BC

After BC

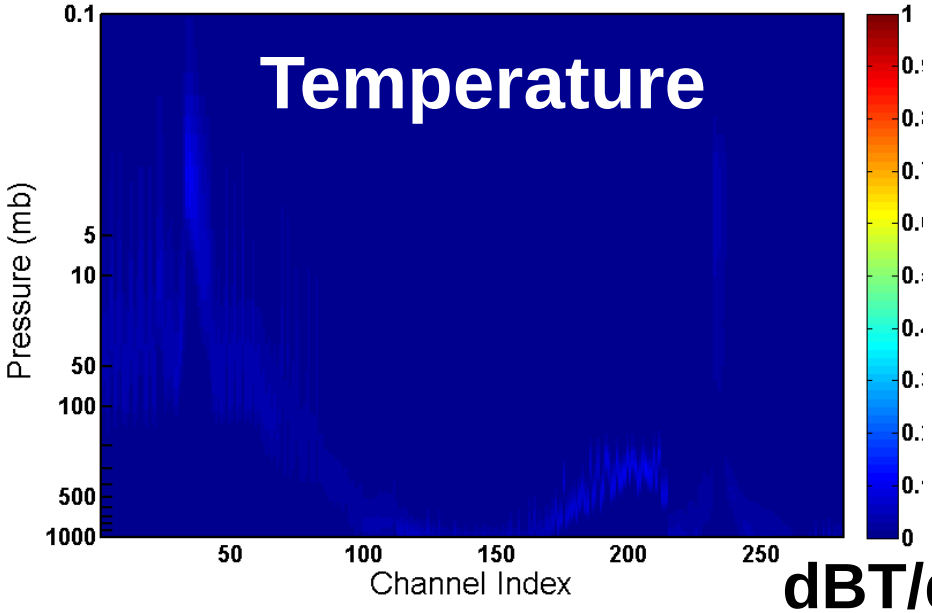
channel 252 (CO2 channel ~672h Pa

Channel 1382 (water vapor channel ~866 hPa

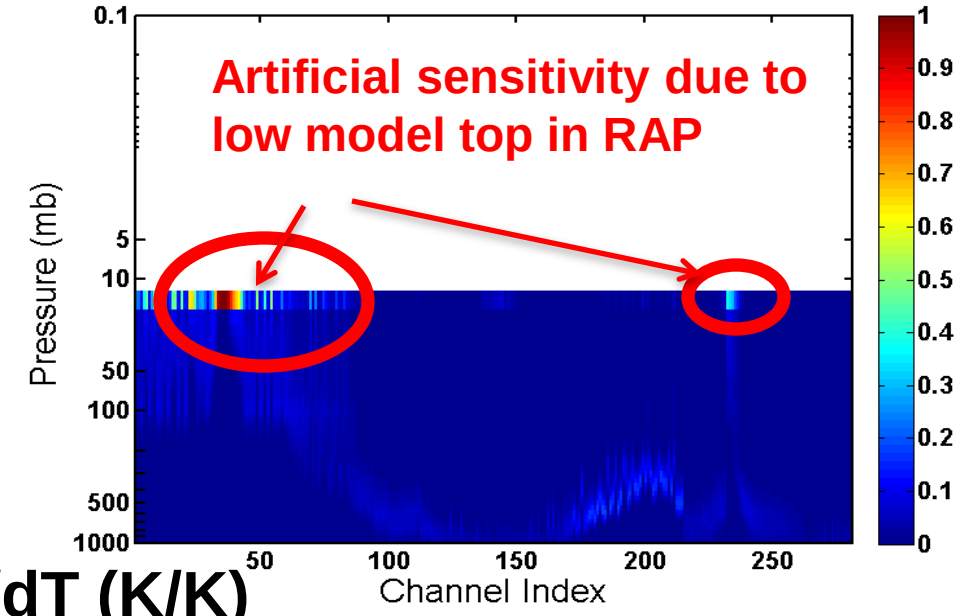
9 day retro run averaged **May08-May16 2010**

AIRS Jacobians for Two Profiles

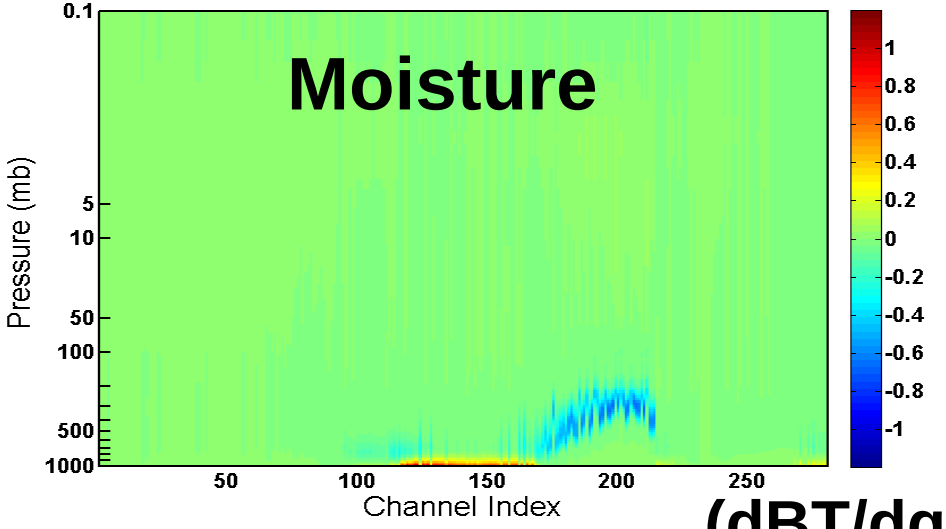
Standard profile (0.01 hPa top)

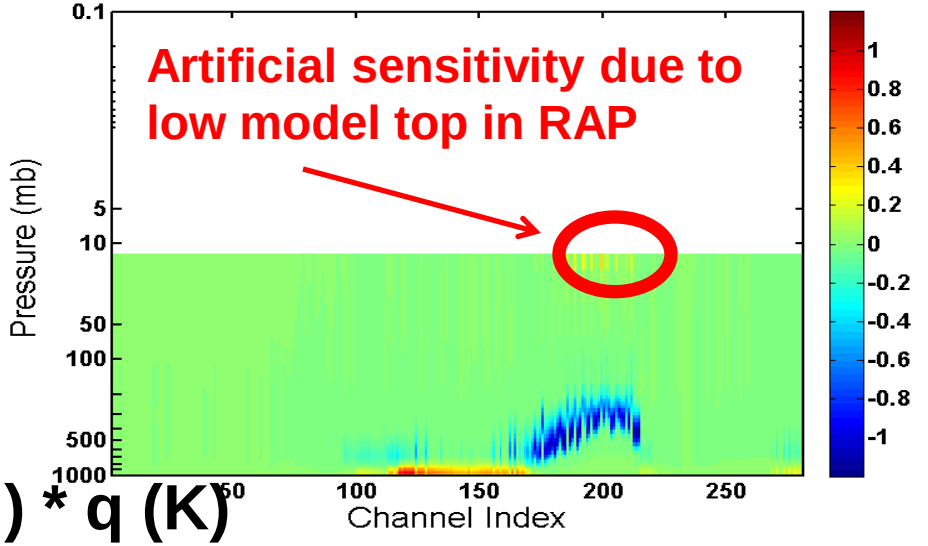


RAP profile (10 hPa top)



dBT/dT (K/K)

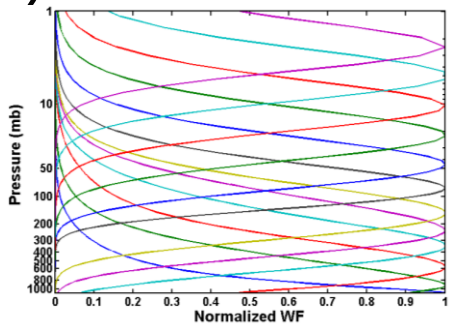




(dBT/dq) * q (K)

Radiance Channels Selected for RAP

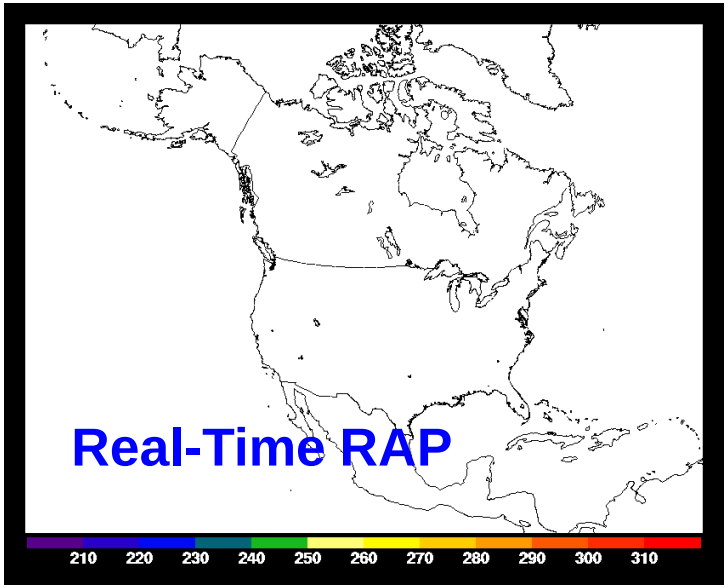
- **AMSU-A** (remove high-peaking channels)
  - metop-a: channels 1-6, 8-10, 15
  - noaa_n15: channels 1-10, 15
  - noaa_n18: channels 1-8, 10,15
  - noaa_n19: channels 1-7, 9-10,15

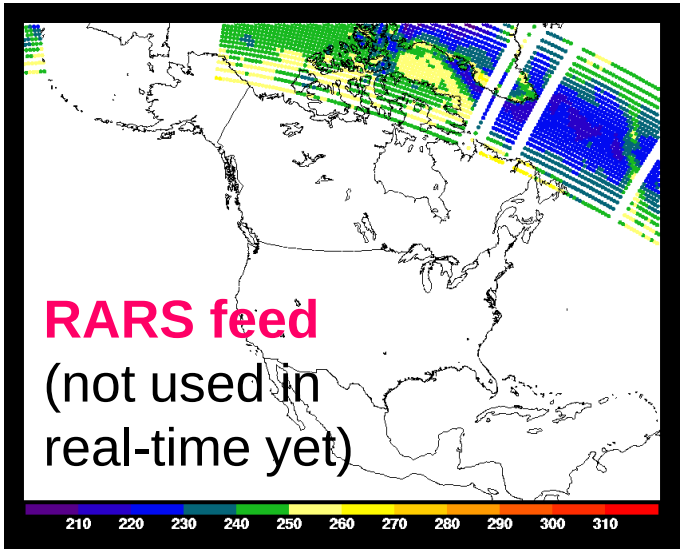


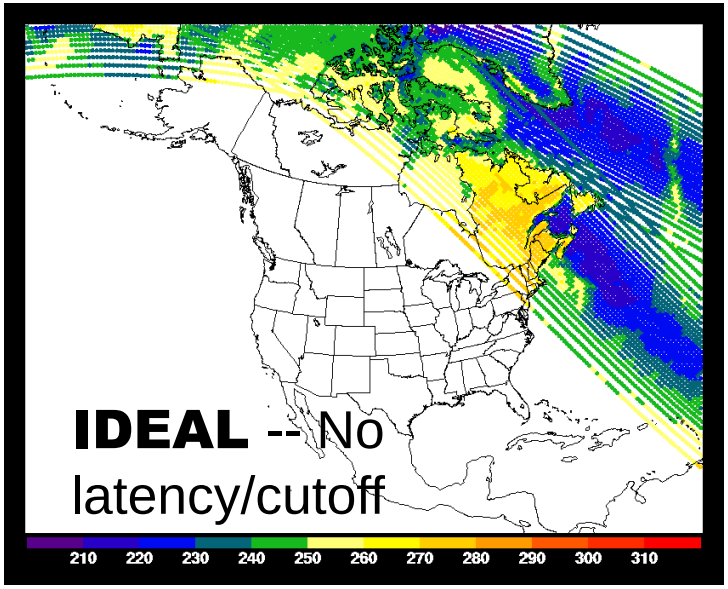
- **HIRS4** (remove high-peaking and ozone channels)
  - metop-a: channels: 4-8, 10-15
- **MHS**
  - noaa_n18, metop-a: channels 1-5;

- **AIRS** (remove high-peaking and ozone channels)
  - Aqua: 68 channels selected from 120 GDAS channel set
- **GOES** (remove high-peaking channels and ozone channel)
  - GOES-15 (sndrD1, sndrD2, sndrD3, sndrD4): channels 3-8,10-15

Real-Time Data Availability -- RARS







18Z May 29, 2013

RARS = Regional ATOVS Retransmission Services

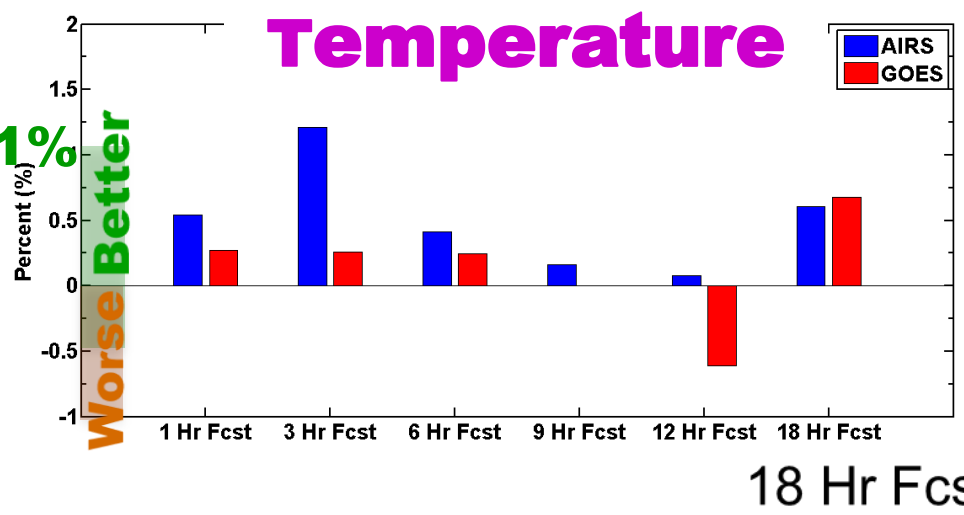
Assuming **+/- 1.5 h** time window

AMSU-A channel 3 from NOAA_18

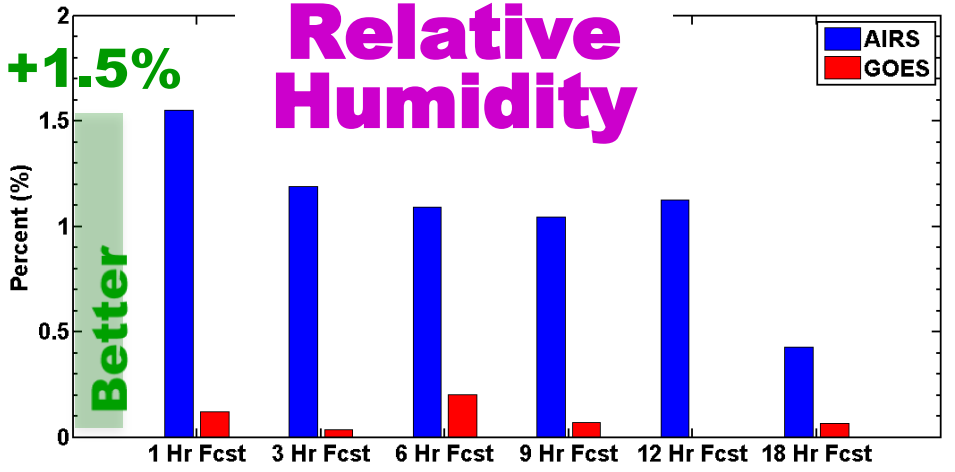
Retrospective Experiments
Set I: new sensors

- **Extensive retro run for bias coefficients spin up**
- **Control run (CNTL) – Conventional data only**
  - **1-h cycling run, 8-day retro run (May 28 – June 4 2012)**
  - **Hybrid EnKF RAP system**
- **AIRS radiance experiment**
  - **CNTL + AIRS radiance data (no latency)**
  - **Using 68 selected channels for RAP**
- **GOES radiance experiment**
  - **CNTL + real time GOES 15 radiance data (sndrD1,sndrD2,sndrD3, sndrD4)**

Impact from AIRS and GOES data (against raob 100-1000 hPa)



18 Hr Fcst



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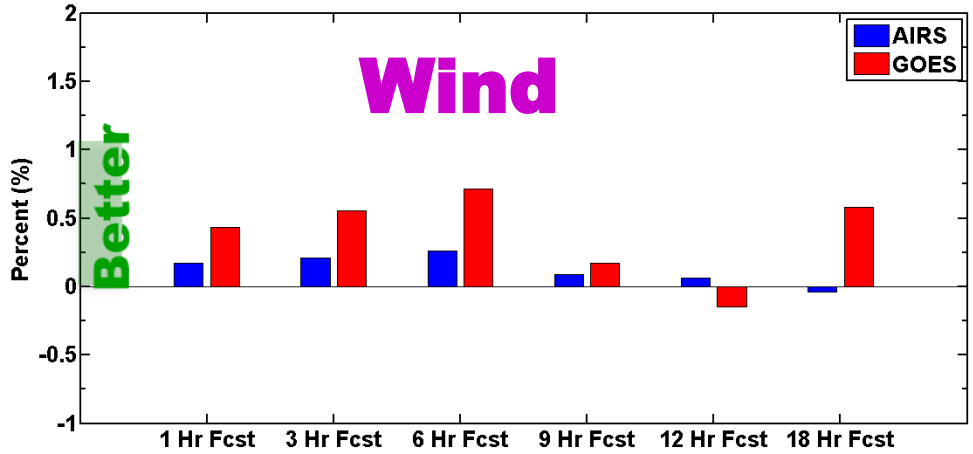


18 Hr Fcst

AIRS

GOES

Normalize Errors

$$E_N = \frac{(CNTL - EXP)}{CNTL}$$

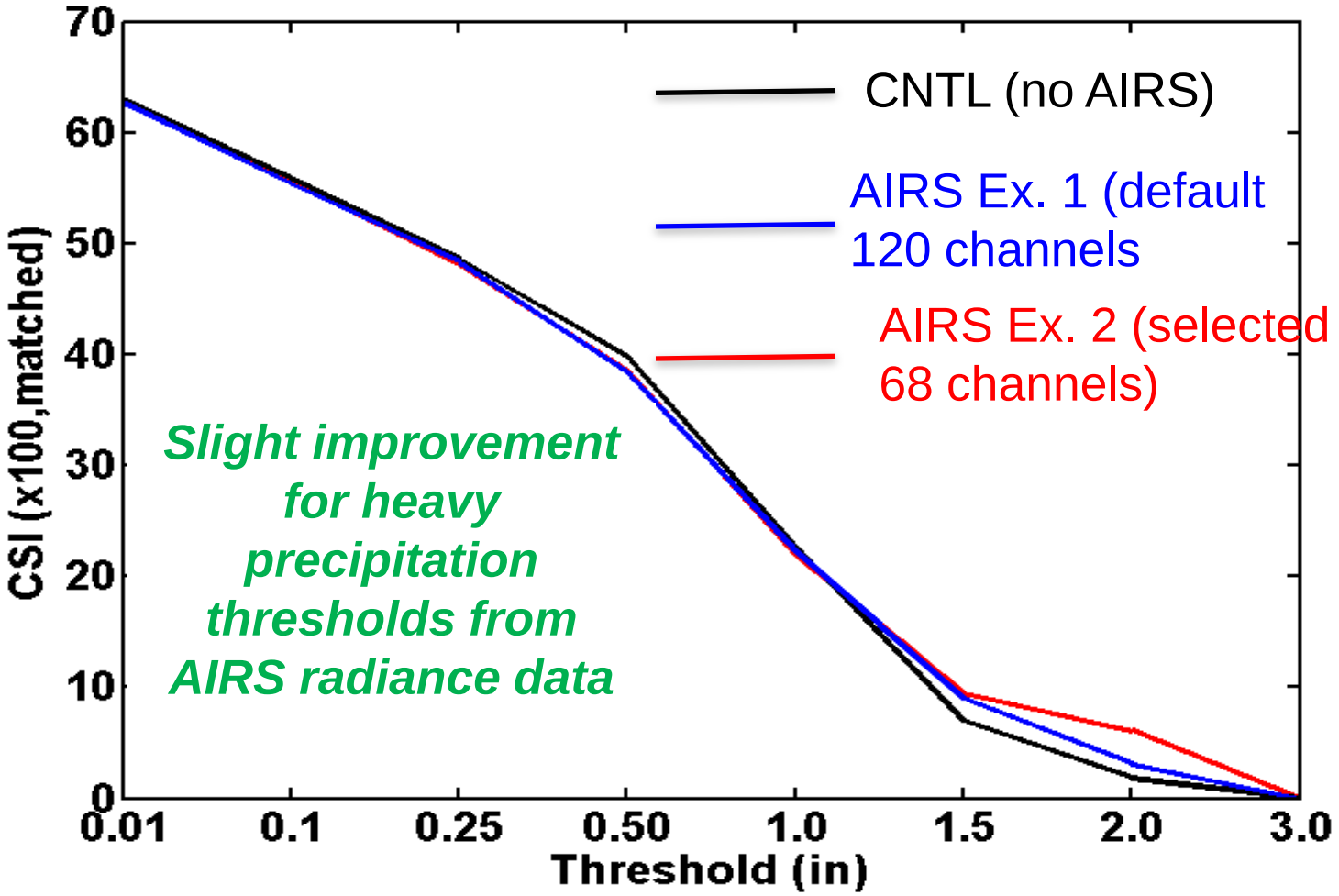
100-1000 hPa RMS mean

May28-June04 2012

upper-air verification

24-h (2 X 12h) CPC Precipitation Verification

CSI by precip threshold
(avg. over eight 24h periods)



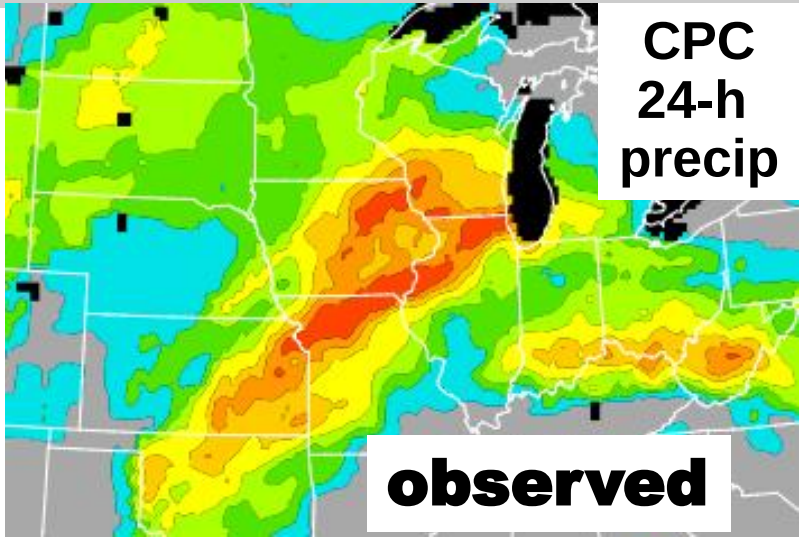
May08-May16 2010

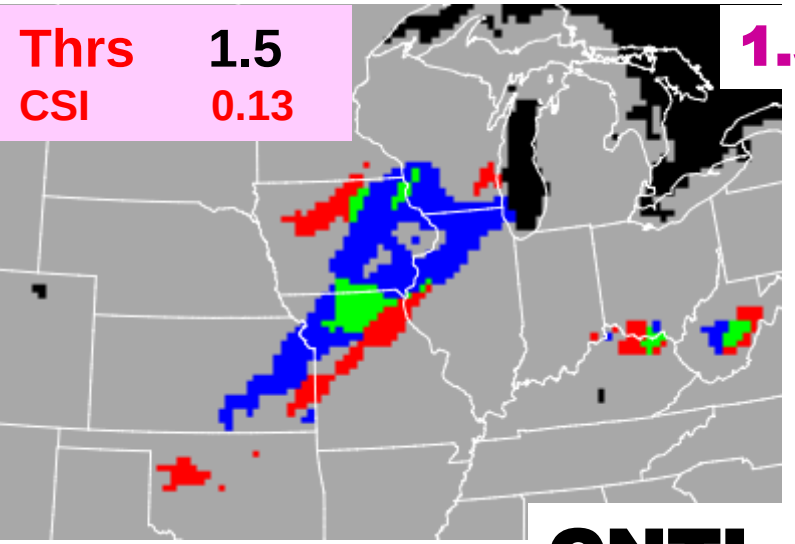
Sample Precipitation Impact

CNTL vs. AIRS Ex. 2 24-h precip. verif

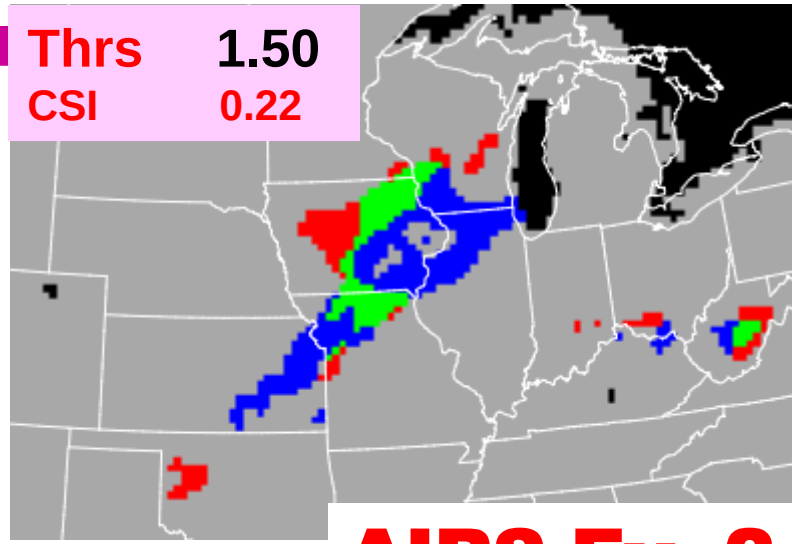
2 x 12h fcst ending 12z 13 May 2010

Verified on common 20-km grid



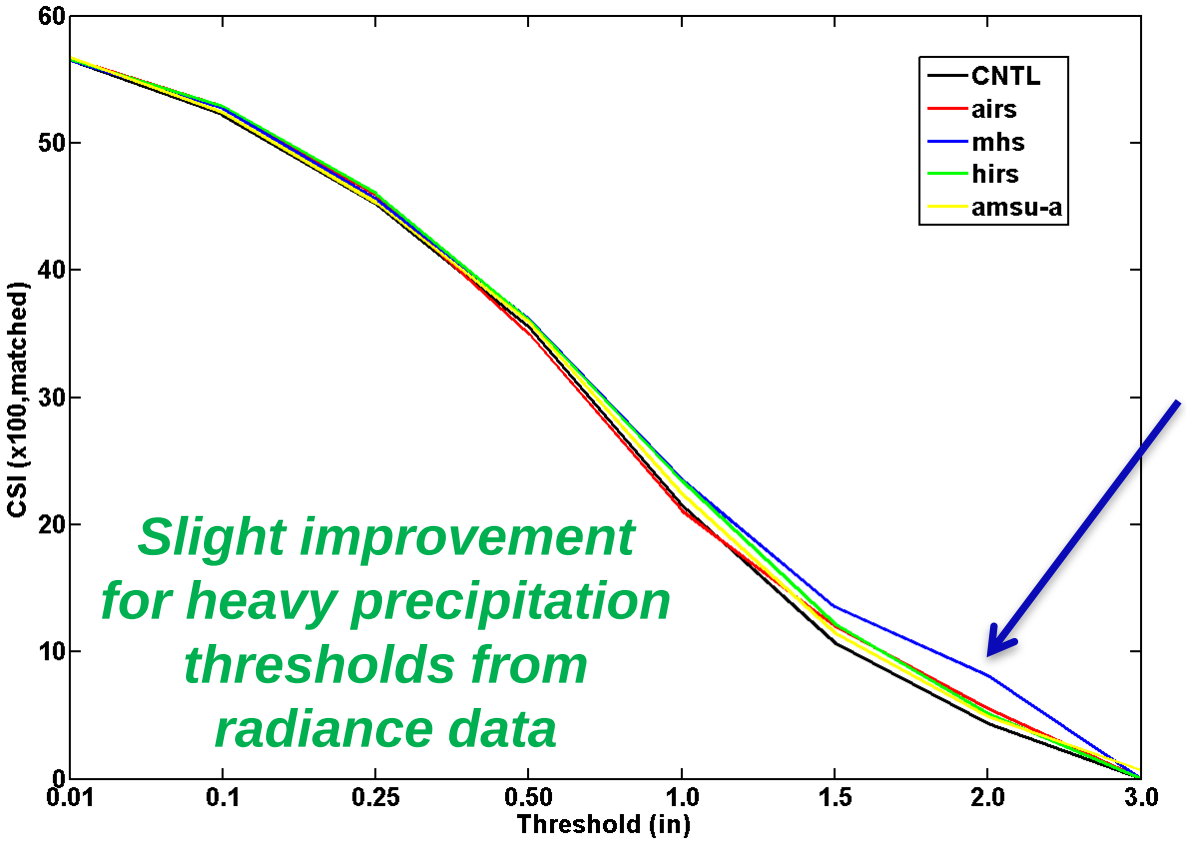


1.5 ” theshold



24-h (2 X 12h) Precipitation Verification

CSI by precip threshold
(avg. over eight 24h periods)



CNTL (conventional data)

AIRS

MHS

HIRS

AMSU-A

MHS data have largest positive impact for heavy precipitation prediction

May08-May16 2010

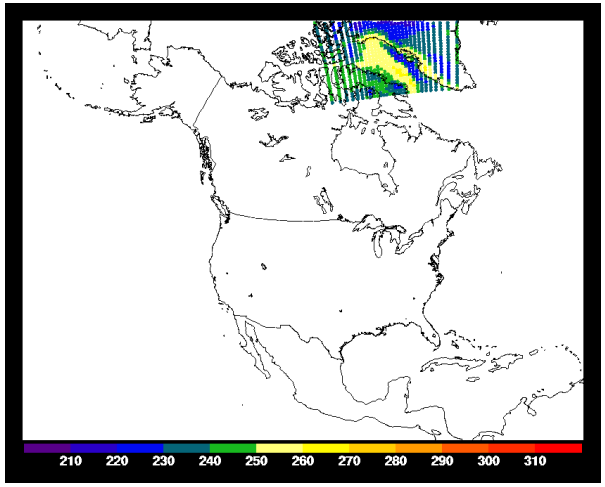
Retrospective Experiments Set II (different data files)

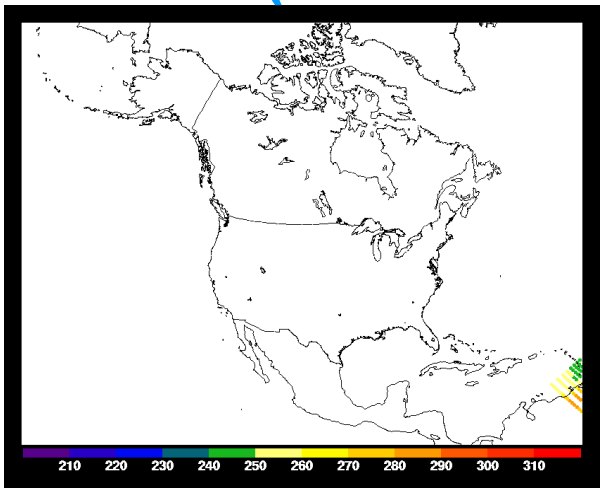
- **Extensive retro run for bias coefficients spin up**
- **Control run (CNTL) – (conventional data only)**
  - 1-h cycling run, 8-day retro run (May 28 – June 4 2012)
  - RAP Hybrid EnKF system
- **Real-time radiance (limited availability)**
  - CNTL + RAP real time radiance data (amsua/mhs/hirs4/goes)
  - Use updated bias coefficients from the extensive retro run
- **RARS + Real-time radiance (better availability)**

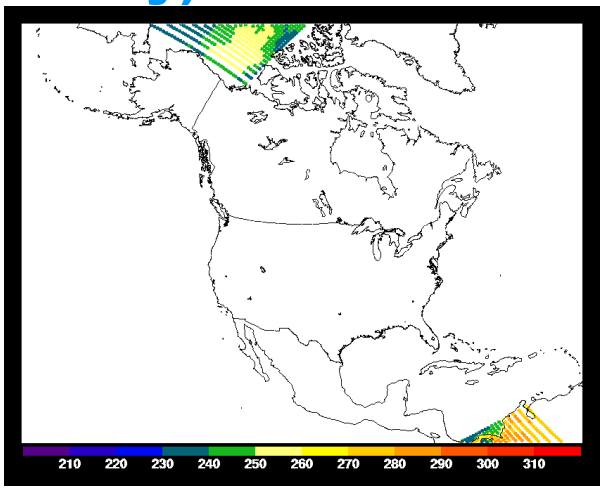
  (RARS = Regional ATOVS Retransmission Services)
- **Full coverage radiance (perfect availability)**
  - Using full data for amsua/mhs/hirs4 (no data latency)

Coverage comparison for the RARS data and the regular feed data

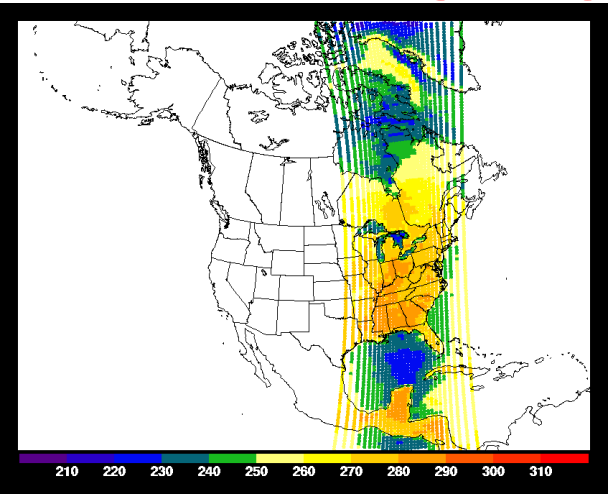
Real-time radiance (limited availability)

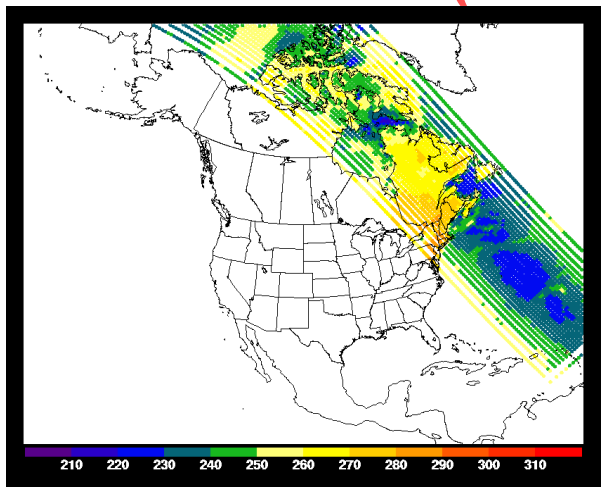


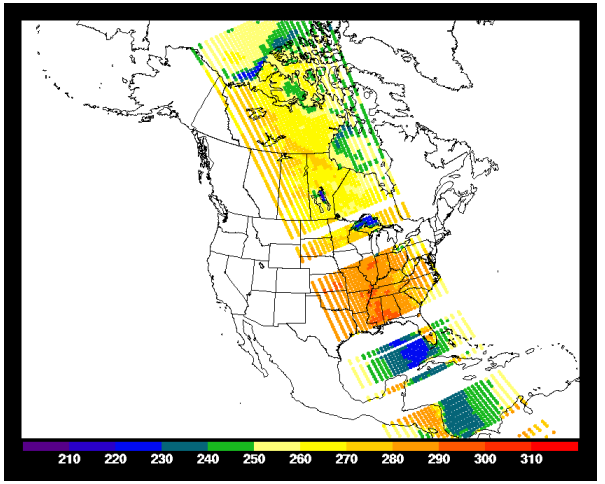




RARS + Real-time radiance (better availability)





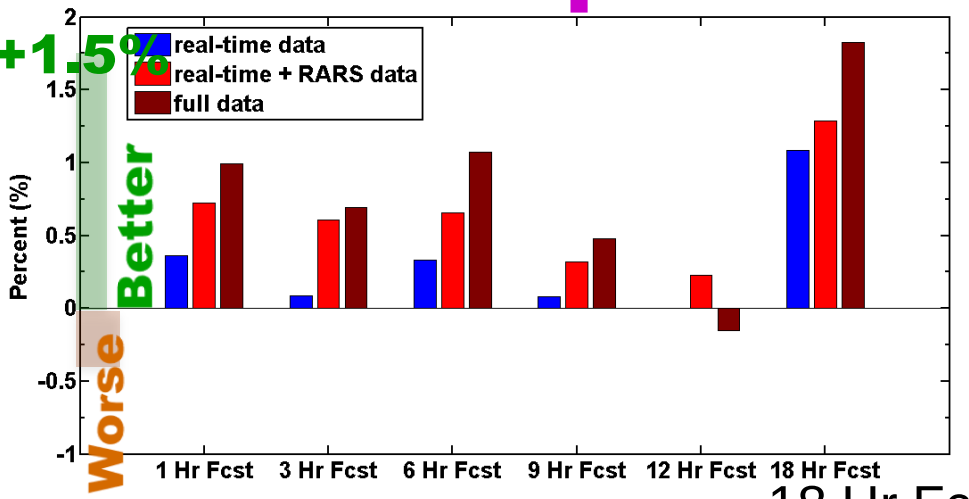


08Z 18Z 19Z

May 29 2012 amsua noaa-19

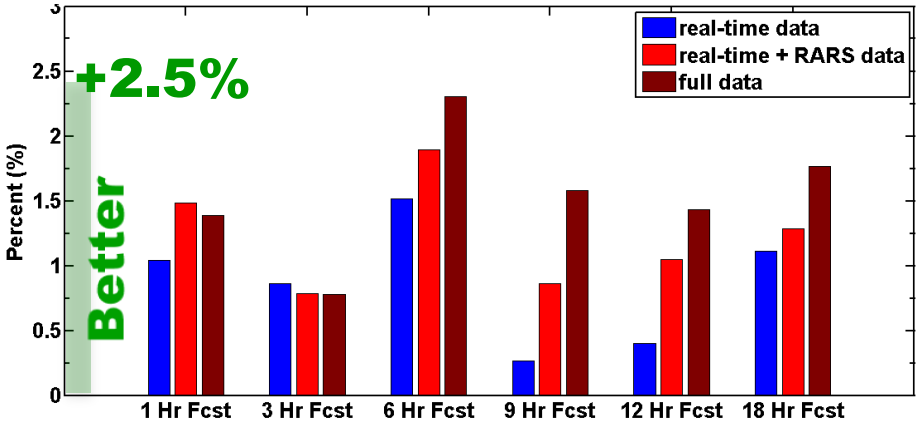
Impact from different data sets

Temperature



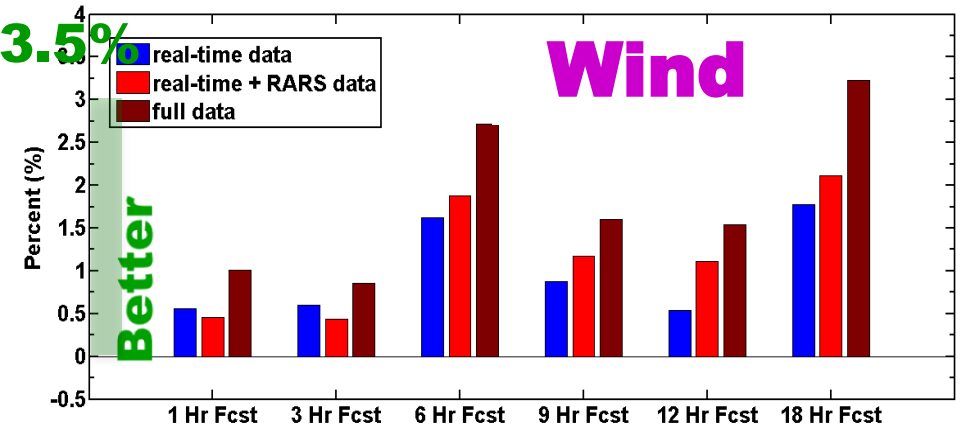
18 Hr Fcst

Relative Humidity



18 Hr Fcst

Wind



18 Hr Fcst

100-1000 hPa RMS mean

May28-June04 2012 retro runs

Real-time data

RARS included

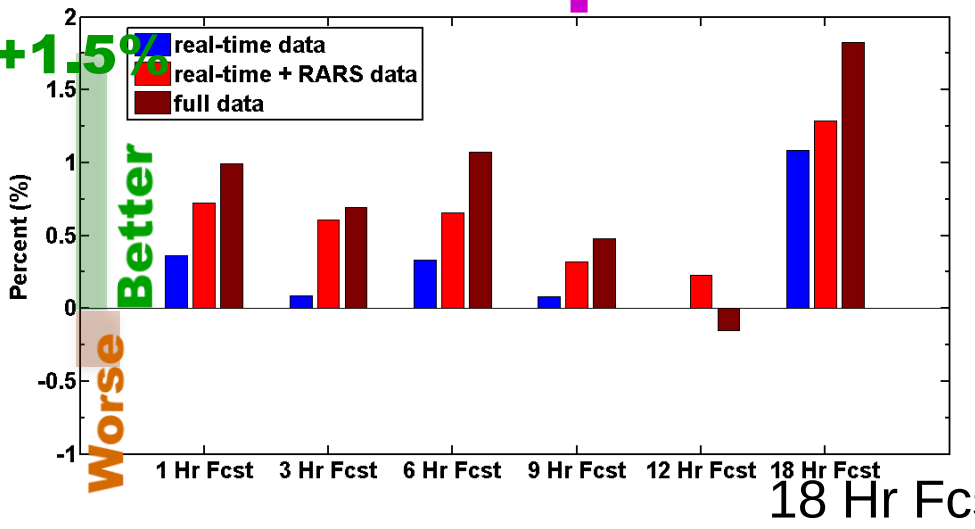
Full data

Normalize Errors

$$E_N = \frac{(CNTL - EXP)}{CNTL}$$

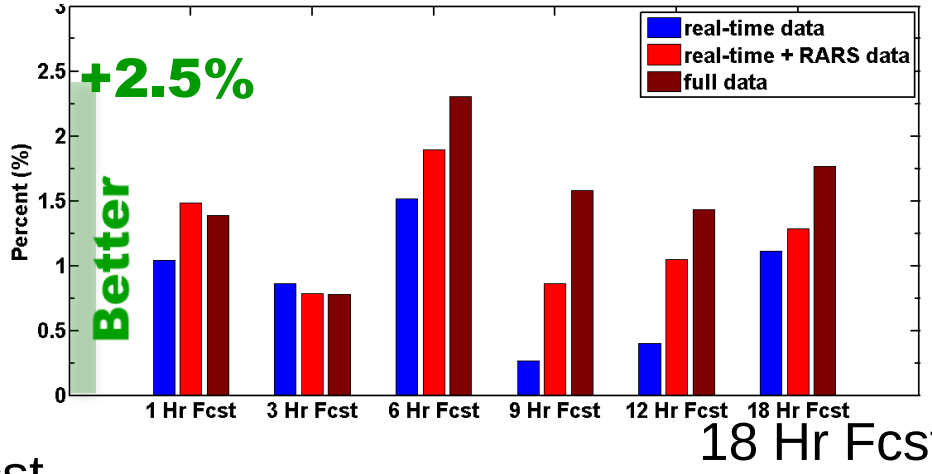
Impact from different data sets

Temperature



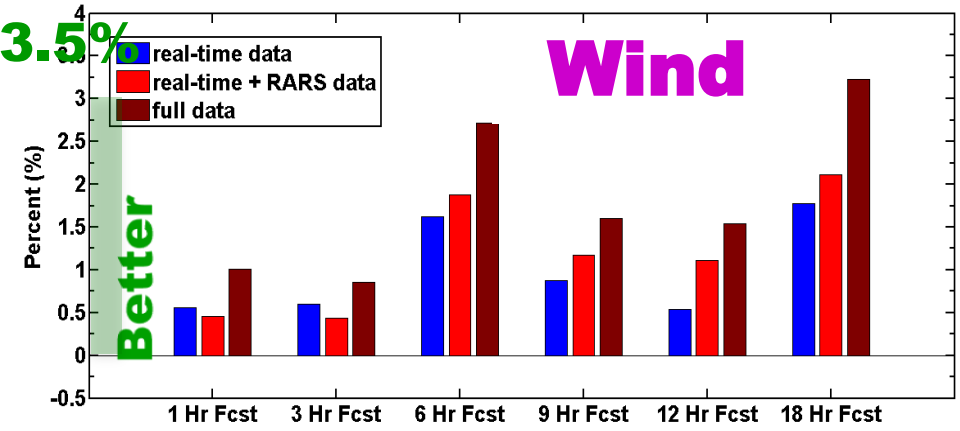
18 Hr Fcst

Relative Humidity



18 Hr Fcst

Wind



18 Hr Fcst

100-1000 hPa RMS mean

May28-June04 2012 retro runs

Real-time data

RARS included

Full data

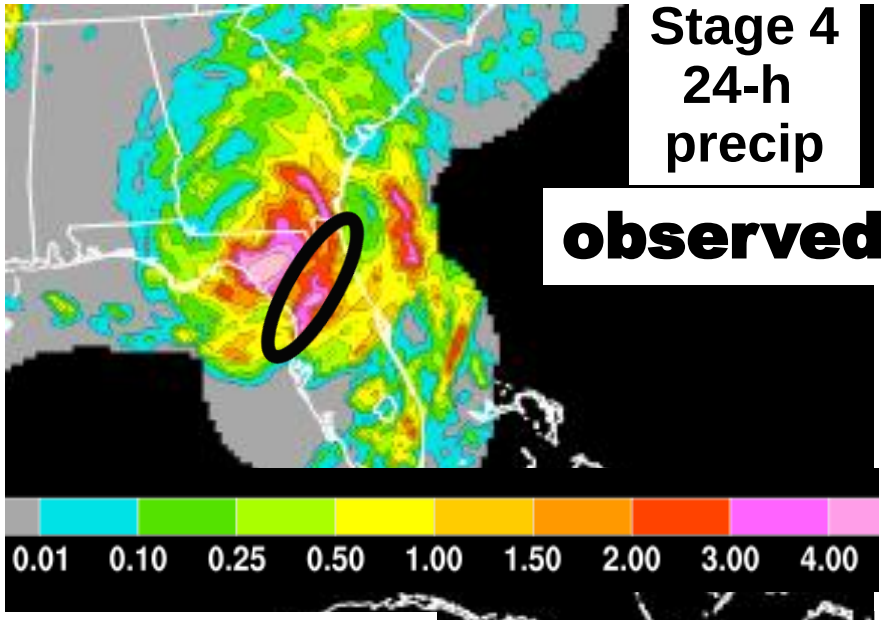
Init Hour	11,23z	9,21z	6,18z	3,15z	0,12z	18,6z
Fcst length	1	3	6	9	12	18
Hrs since GFS	2	0	9	6	3	9

GFS partial cycle at 09z and 21z

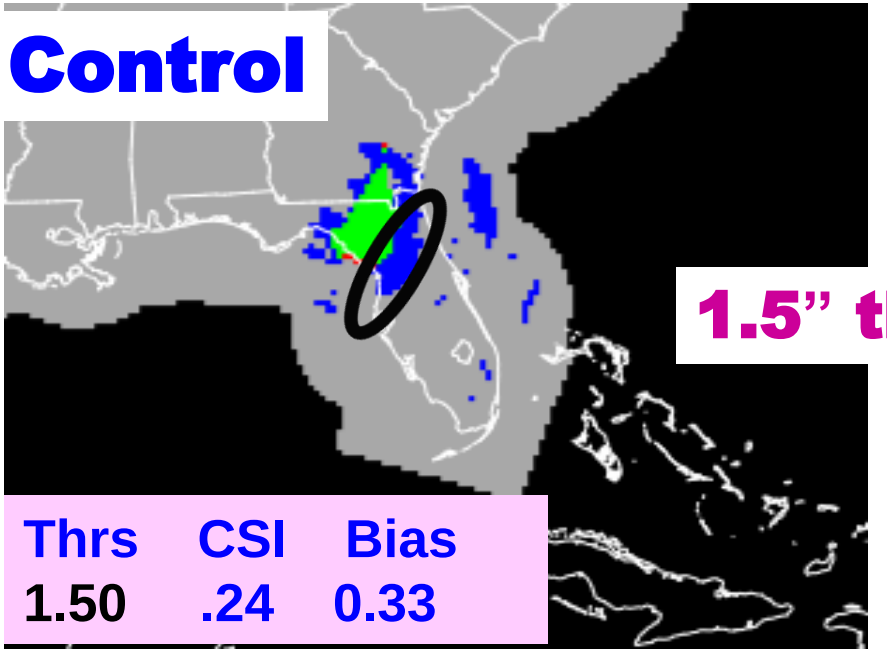
Precipitation Verification

Control
vs.
Radiance (RARS included)

2 x 12h fcst
ending 12z
29 May 2012



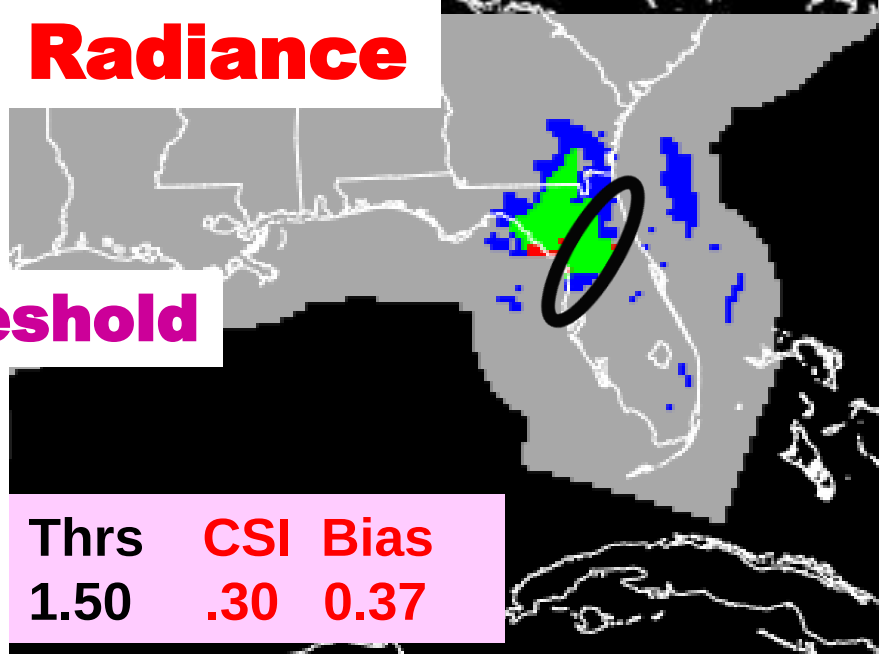
Control



Thrs	CSI	Bias
1.50	.24	0.33

1.5” threshold

Radiance



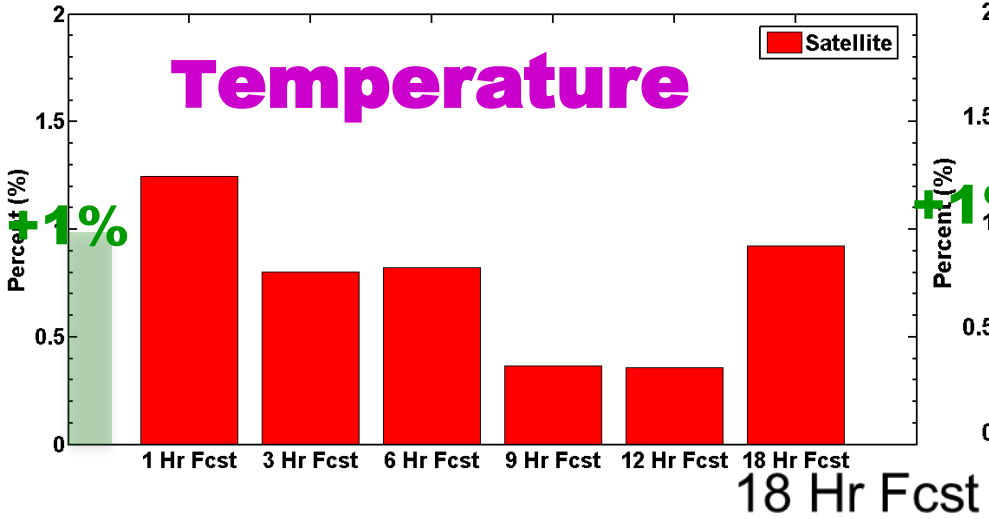
Thrs	CSI	Bias
1.50	.30	0.37

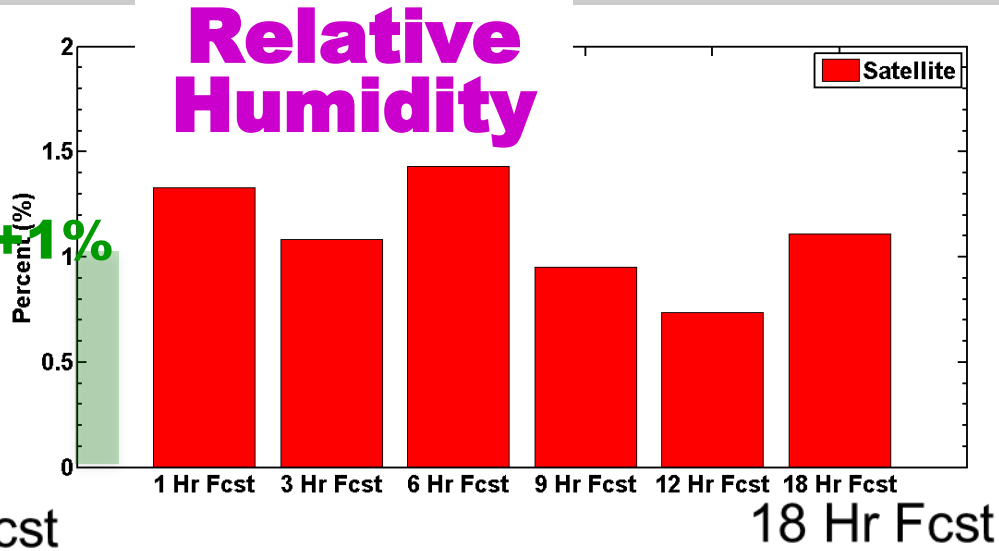
Real-time RAP Experiments

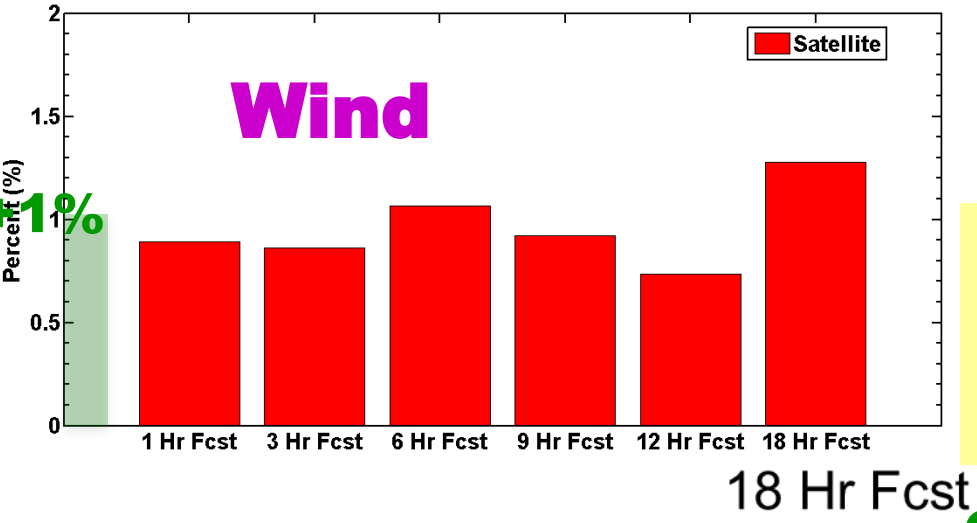
- **Real-time** RAP hybrid systems (RAP V2) on Zeus:
  - 1-h cycling with partial cycle
  - real-time data
- **6 month time period**

  (Jun-July, Oct-Dec, 2013, Jan, 2014)
- **NO radiance**
  - conventional data only
- **WITH radiance**
  - conventional data + operational used radiance data (AMSU-A, HIRS4, MHS)

Real-time % improvement from radiance DA







Radisonde verification

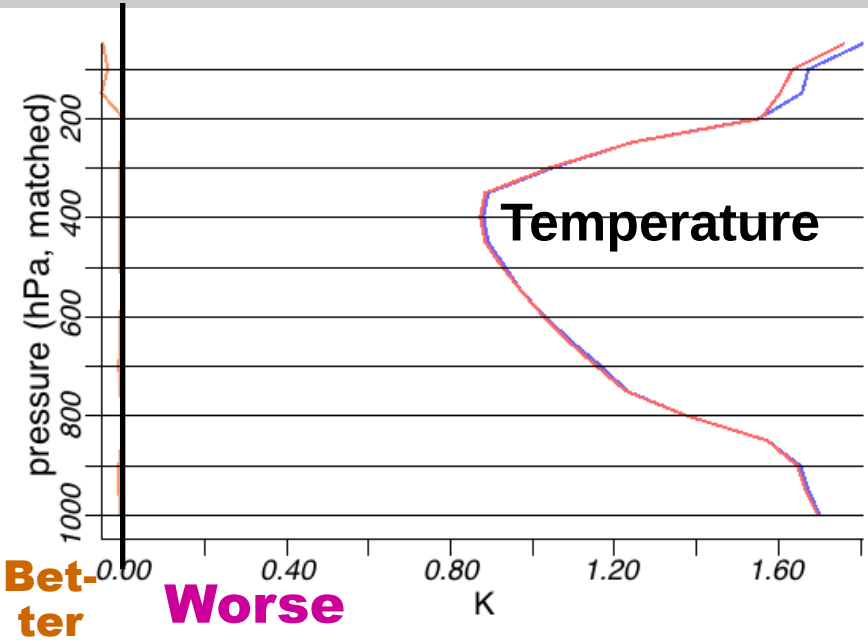
6 month REAL-TIME test

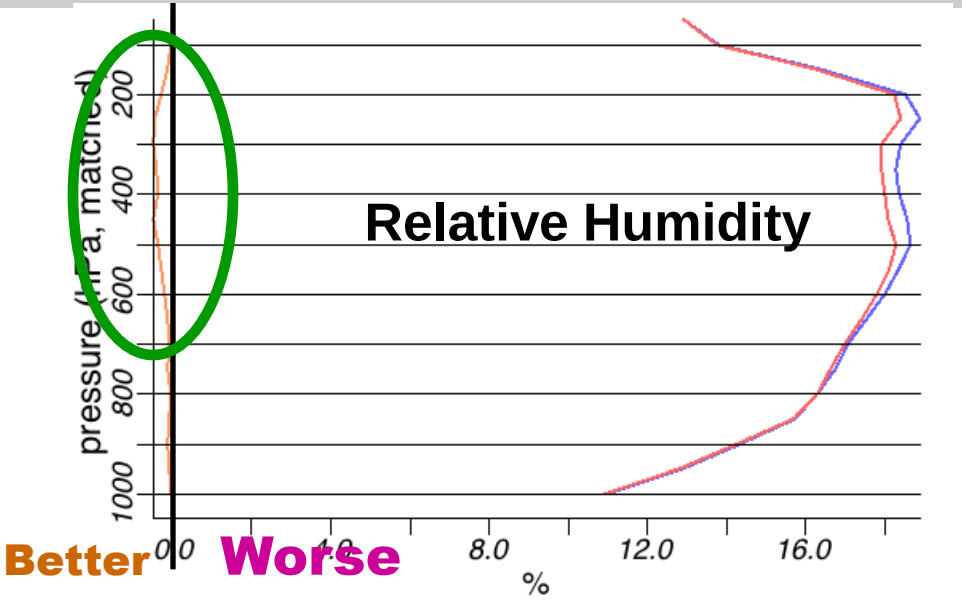
Init Hour	11,23z	9,21z	6,18z	3,15z	0,12z	18,6z
Fcst length	1	3	6	9	12	18
Hrs since GFS	2	0	9	6	3	9

GFS partial cycle at 09z and 21z

100-1000 hPa RMS mean

6-h Forecast RMS Error



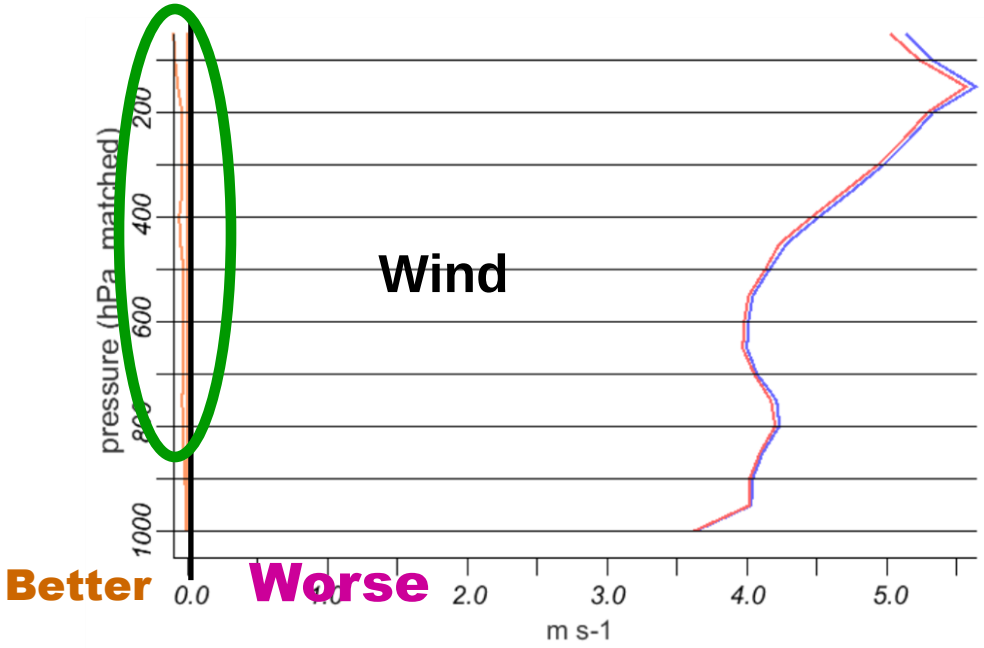


WITH radiance

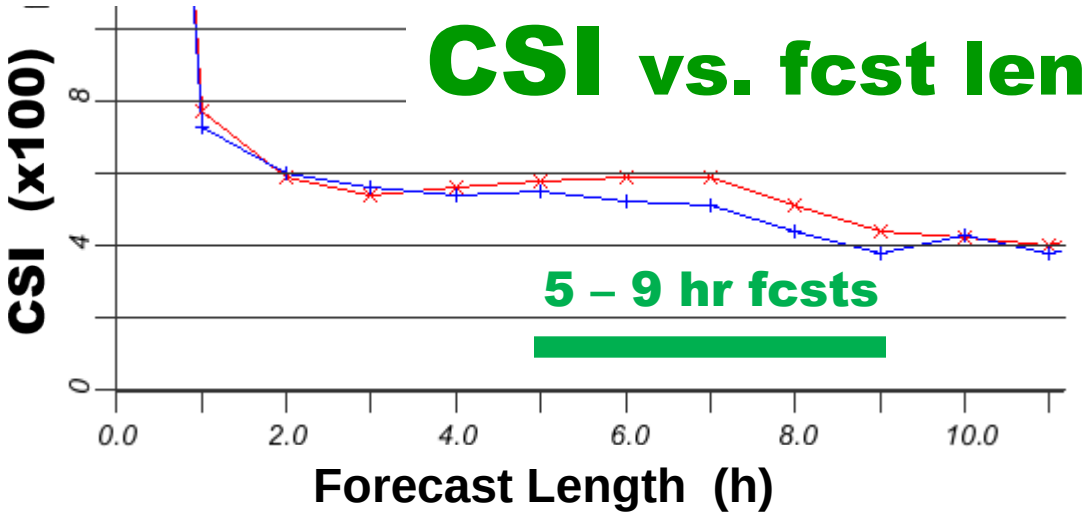
NO radiance

upper-air verification

Real-Time 6-month average
(limited data coverage)



HRRR Radar reflectivity verification

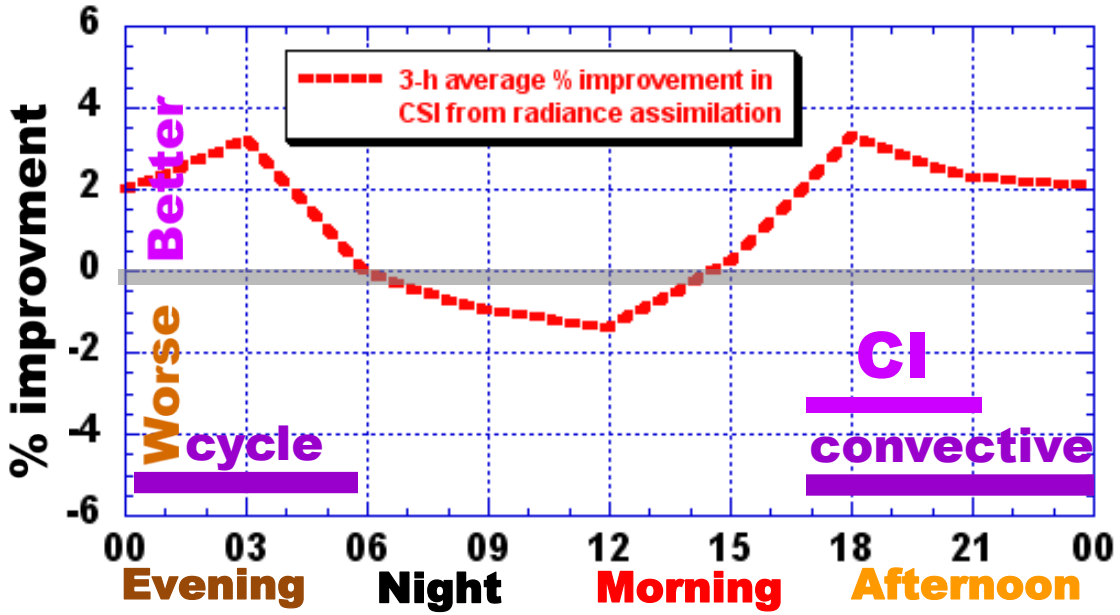


WITH RAP radiance

NO RAP radiance

40 dBZ
20 km scale
Eastern US

Retro runs matching real-time



CSI % improvement from radiance assim vs. valid time of day

(all forecast lengths) -- 3 adjacent hourly values averaged to 3-hourly times

30 dBZ
20 km scale
CONUS

May 29 – June 04 2012 (34 HRRR retro runs)

Summary of radiance updates for RAP V3

- Included new sensors/data
  - GOES sounding data from GOES-15
  - amsua/mhs from noaa-19 and metop-b ;
- Included the RARS data (Just on Zeus now)
- Removed some high peaking channels to fit the model top of RAP and removed the ozone channels
- Implemented the enhanced variational bias correction scheme with cycling

Conclusions

- AIRS and GOES data have slightly positive impact
- RAP real-time radiance data have slightly positive impact and the RARS data provide additional benefits
- 6-month real time runs showed consistent positive impact (around 1%) from radiance data in RAP
- Assimilation of satellite radiance data in morning RAP runs, improving mesoscale environment, leading to slightly better HRRR forecasts of convective initiation and evolution
- Recommendations for RAP V3 updates (R2O, included, planned operational implementation in 2015)

Future work

- Other new data (focusing on hyperspectral data)
  -- ATMS and CrIS from NPP
  -- IASI from metop-a/b
  -- ABI from GOES-R (when available)

- Increase RAP model top and model levels for better use of hyperspectral data in regional model and better bias correction (for experiment and research purpose)

- Real-time data latency problem:
  - Partial cycle strategy
  - Use direct read out data